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NUCLEAR LANGUAGE
and how we learned to pat the bomb

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Pakistan's bomb-making capacity

The gas centrifuge enrichment plant at Kahuta, Pakistan could be producing barely enough material to make one nuclear weapon per year, or as many as 12, depending on the material used and the number of working centrifuges.

by David Albright

DESPITE GROWING evidence that Pakistan is close to possessing nuclear weapons, there is still little public information about the amount of weapon-grade uranium that it could produce. The latest round of speculation began with a November 4, 1986, *Washington Post* article citing classified U.S. intelligence reports that Pakistan had produced an unspecified amount of weapon-grade uranium (enriched to over 90 percent in the relatively scarce isotope uranium 235) at its heavily guarded gas centrifuge enrichment facility at Kahuta.

Since 90 percent material is ideal for making nuclear explosives, Pakistan has apparently crossed the last, most important technical barrier to acquiring nuclear explosives. The *Post* gave no indication of the amount of weapon-grade uranium produced so far, but other information suggests that at the time of the report Pakistan had less than 15–30 kilograms of weapon-grade uranium, the amount typically mentioned by nuclear weapons designers as necessary to make a nuclear explosive.[1]

Pakistan maintains that it has produced only low-enriched uranium for peaceful purposes. It says that it needs Kahuta to produce low-enriched uranium to fuel a 900-megawatt light-water reactor that it hopes to purchase from abroad and operate in the mid-1990s. Yet, in a *Time* magazine interview published on March 30, Pakistani President Mohammed Zia ul-Haq declared: "Pakistan has the capability of building the Bomb. You can write today that Pakistan can build a bomb whenever it wishes." Zia added, however, that Pakistan does not intend to build nuclear weapons.

Press reports from 1986 say that Pakistan expects to be able to produce about 10 kilograms of weapon-grade uranium a year from 1987 onward.[2] Unfortunately, these reports give little indication of the basis for the estimates or of their reliability.

As a first step in evaluating the amount of weapon-grade uranium Kahuta can produce, I have used publicly available information to estimate Kahuta's enrichment capacity under a variety of conditions. These estimates depend primarily on the number and the capacity of gas centrifuges at the plant. They also depend, however, on the way the centrifuges are arranged and, in particular, on the amount of uranium 235 in the uranium that is used as input or "feed" into the process. For example, the 1984 pledge by Pakistan to enrich uranium only to 5 percent uranium 235 gives the false impression that from this point enrichment to over 90 percent is a long way off. In fact, roughly three-quarters of the process is completed after natural uranium, or 0.7 percent uranium 235, is enriched to 5 percent.

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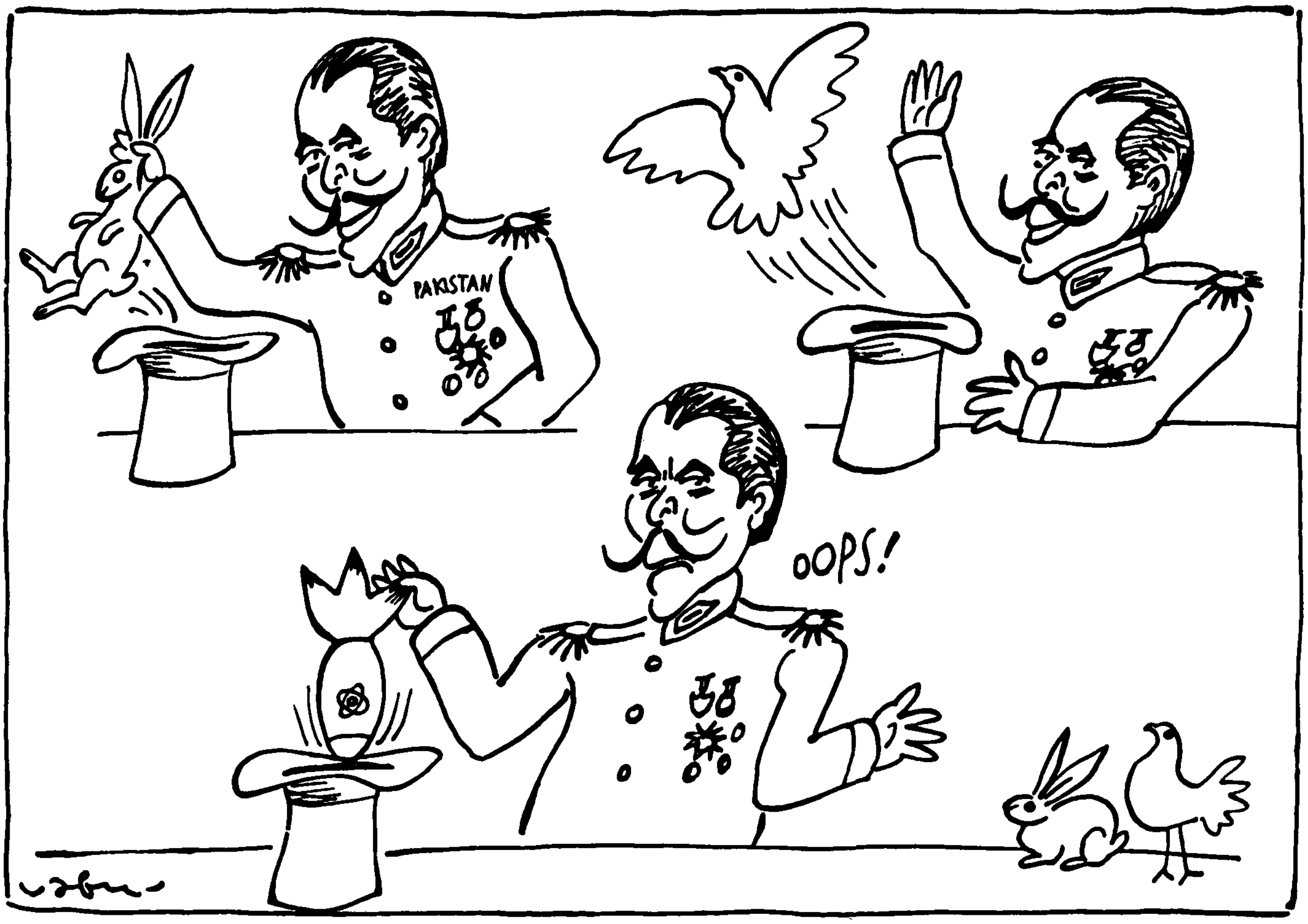
GAS CENTRIFUGE enrichment separates uranium isotopes (uranium atoms that differ from one another by the number of neutrons they contain) by subjecting uranium gas to a strong centrifugal force in a rotating cylinder. Heavier isotopes are forced to the periphery of the rotating cylinder, where they are separated from their lighter counterparts. One distinct advantage of this process over the more common gaseous diffusion enrichment process, now used almost exclusively in the nuclear weapons states, is that smaller, more efficient enrichment plants can be built. A relatively small number of centrifuges can be connected into a cascade, which enriches in stages by passing material increasingly concentrated in uranium 235 through successive centrifuges. Each gas centrifuge, however, can hold only a small amount of uranium gas, requiring many centrifuges to produce enough weapon-grade uranium for a nuclear explosive.

Two recent news reports cite differing estimates of the number of centrifuges at Kahuta. In the spring of 1986 the *Foreign Report* of the *Economist* and *Der Stern* stated that Kahuta had 14,000 centrifuges. On August 9, 1986, Islamabad's English daily newspaper, *Muslim*, reported that Kahuta was "rumored to have 1,000 centrifuges, against a planned capacity of 2,000–3,000 centrifuges." This estimate is similar to an earlier one in the June 21, 1984, *Congressional Record* by Senator Alan Cranston, who said that by 1983 the Pakistanis had completed nearly 1,000 centrifuges at Kahuta. U.S. government sources confirmed that 14,000 centrifuges is a more accurate count than the lower estimates, but they could give no indication of the number actually operating.

Pakistani scientists have experienced difficulty getting their machines to work because design faults and inadequate materials have led to high failure rates for the centrifuges. A former worker on the enrichment project, who left the program several years ago, said in *Der Stern*: "Every week, there would be centrifuges exploding all over the place, because they did not withstand the tremendous centrifugal forces, because there were imbalances in the steel, or because of material fatigue."[3]

The centrifuges at Kahuta are supercritical machines. Such centrifuges have rotors operating above critical rotational frequencies or resonances. That is, certain rotor



Abu, The [Calcutta] Telegraph, *India*

speeds create resonant vibrations, and if the rotor remains at or near resonance for any length of time, the vibration can increase until the rotor or its bearings are wrecked. These centrifuges, therefore, must be operated at speeds away from resonant frequencies and must be able to accelerate rapidly through resonant speeds.

Because of the difficulties in getting the centrifuges to work, Pakistani scientists probably are not operating 14,000 centrifuges, although this many might have been built. More likely, the number of operating centrifuges is closer to 1,000. Pakistan, however, can be expected to increase the number operating.

COUNTING CENTRIFUGES does not give a full picture of the capacity at Kahuta, which also depends on the separative work capacity of each centrifuge, measured in "separative work units." One can infer some details about the capacity of Pakistani centrifuges from public information about Urenco centrifuges. This is because Abdul Qadeer Khan, the founder of the Pakistani enrichment program, reportedly stole the designs for these centrifuges when he worked at a Dutch engineering firm whose parent company played an important role at the Urenco enrichment facilities at Almelo, Netherlands. Khan worked there from 1972 to 1975, and during this time gained access both to secret technical data about centrifuges in the two pilot facilities and to detailed lists of the equipment used in them.[4]

Although great secrecy surrounds details about all Urenco centrifuges, a German-designed centrifuge used in a pilot plant at Almelo in the mid-1970s, and later in Almelo's commercial enrichment plant, reportedly had an estimated separative work capacity of five units per year.[5] Since Khan had access to several types of centrifuges, estimating the separative capacity of the Kahuta centrifuges is highly uncertain. For example, Khan could have stolen the design for an advanced centrifuge with a capacity higher than five units per year, or he could have opted for a proven design with lower capacity. For the purposes of this study, however, five units per year is a reasonable estimate of the centrifuge capacity at Kahuta.

It takes 238 separative work units to produce one kilogram of 94 percent enriched weapon-grade uranium, assuming the feed one starts with is natural uranium and that a 0.2 percent concentration of uranium 235 is left in the waste. Therefore, if Kahuta has 1,000 operating centrifuges, each with a separative capacity of 5 units per year for a total capacity of 5,000 per year, it could produce 21 kilograms of weapon-grade uranium annually. If Pakistan ever operated 14,000 centrifuges, it could produce nearly 300 kilograms of weapon-grade uranium each year. (If Pakistan does, in fact, buy a 900-megawatt light-water reactor, then it may need all of these centrifuges plus about 4,000 more to produce enough enriched uranium to fuel it.)

As mentioned earlier, a nuclear explosive requires between 15 and 30 kilograms of weapon-grade uranium. The exact quantity depends on the design of the explosive and the sophistication of the weapons program: the International Atomic Energy Agency (IAEA) estimates that a crude nuclear explosive requires about 25 kilograms of weapon-grade uranium; a design using 20 percent enriched uranium would require several hundred kilograms of uranium. Since little is known about the design of Pakistan's nuclear explosives, the IAEA value will be used.

Under the above assumptions, 1,000 operating centrifuges can produce 21 kilograms of weapon-grade uranium annually, or slightly less than the amount required for one bomb a year; similarly, 14,000 centrifuges correspond to 12 explosives a year.

KAHUTA COULD PRODUCE dramatically more weapon-grade uranium each year if it used slightly enriched uranium as a feed instead of natural uranium feed. Pakistan

Bombs without test blasts?

The same *Washington Post* story that reported weapon-grade uranium production also said that Pakistan had detonated two conventional high-explosive devices in 1986 as part of its continuing efforts to build implosion-type nuclear weapons. (Implosion designs rely on the precise detonation of conventional explosives within the warhead to compress a fissile uranium core to a supercritical, explosive mass.) To avoid a direct confrontation with its neighbors and the United States, Pakistan might choose not to conduct a full-scale nuclear test. It could, however, develop a nuclear arsenal of fission weapons without full-scale nuclear testing.

Press accounts in 1984 quoted Reagan administration officials as saying that the People's Republic of China had supplied Pakistan with information about the design of nuclear weapons.[1] It is impossible to confirm these reports, but if true, Pakistan might only need to test the non-nuclear components of its device to be able to build nuclear weapons. If these press accounts turn out to be untrue, however, Pakistan still might not need to conduct full-scale nuclear tests.

A recent study by several U.S. weapons designers concluded that a terrorist group could construct a relatively unsophisticated nuclear implosion device with a yield in the kiloton range without full-scale nuclear explosive testing.[2] The designers estimated that the device would require about 25 kilograms of weapon-grade uranium. Pakistan, with substantially more resources available to it than a terrorist group, could more easily develop crude nuclear weapons that do not need testing. This result is not surprising; the United States also correctly concluded that it did not need to test the Hiroshima bomb. This bomb, however, had a gun-type design, and Pakistan is believed to be using an implosion design.

By testing the non-nuclear triggering package with a dummy core of ordinary uranium, Pakistan could gain confidence and make improvements in the design of its nuclear explosives, particularly if these tests are accompanied by extensive measurements and theoretical calculations. Although they would not produce a nuclear reaction, these field tests would provide Pakistan with important information about both the performance of its implosion system and the initiation of a nuclear explosive.

There are several ways to measure what goes on inside a dummy core during a test. Pakistan's apparently unsuccessful attempts to operate flash X-ray machines, which can take split-second photos through solid materials to show what takes place during a test, have received widespread attention. But other, easier to obtain, technologies might also be useful. For example, electrical conducting pins placed at various depths within a hemisphere or three-quarters of a sphere of uranium could measure the arrival times of the high-explosive shock wave. By collecting this data, Pakistani scientists could compare arrival times of the shock wave with their calculated values and could also determine asymmetries in the shock wave. A spherically symmetrical explosion all around the core is required to compress weapon-grade uranium to supercritical mass. An accurate prediction of arrival times is a good test of theoretical calculations and improves confidence in the design.

Without full-scale testing, Pakistan could even reduce the weight and size of its nuclear explosives to make them more deliverable on its U.S. F-16 or French Mirage aircraft, although the amount of weapon-grade uranium required for such a warhead might not be reduced very much. If it reduced the size and weight of the implosion trigger, it would have to reduce the amount of high explosive in the weapon, thus reducing the amount of energy available to bring weapon-grade uranium to supercritical mass. A more effective implosion design, however, might reduce the amount of nuclear material necessary for an explosive, although such a design might not reduce the overall size and weight of the device.[3]

Pakistan could determine that its design works and could also improve that design, while avoiding full-scale nuclear tests, through "zero yield" nuclear testing. With this type of test, a small, weapon-grade uranium core is exploded to create a nuclear yield high enough to measure with radiation detectors placed close to the explosive, yet not high enough to exceed the power of the blast from the conventional high explosive used to compress the core. These tests, however, require several kilograms of weapon-grade uranium and some sophistication in order to avoid achieving a much larger yield than intended. Theodore Taylor, a former nuclear weapons designer, suggests that one way to avoid this risk is to plan several tests, starting with a small amount of weapon-grade uranium to insure that a high yield will not be reached by mistake. From this base, the experimenters increase the amount of uranium used in each blast as indicated by test results and corresponding calculations.[4]

Only nuclear weapons experts can determine the performance limits of fission weapons that do not undergo full-scale nuclear testing. But these limitations will not prevent Pakistan from deploying nuclear weapons that will work without ever having undergone full-scale nuclear testing. ☐ —*David Albright*

[1] Leonard Spector, *Going Nuclear* (Cambridge, Mass.: Ballinger, 1987), p. 195.

[2] J. Carson Mark et al., "Can Terrorists Build Nuclear Weapons?" in Paul Leventhal and Yonah Alexander, eds., *Preventing Nuclear Terrorism*, (Lexington, Mass.: Lexington Books, 1987), pp. 55–65.

[3] Ibid., p. 64.

[4] Theodore Taylor, "Nuclear Testing Is a Pandora's Box," *Public Interest Report* (Dec. 1986).

has on hand an undisclosed amount of low-enriched uranium, which it has been producing since at least early 1984.[6]

Because of the increased failure rates while stopping or starting centrifuges, producing weapon-grade uranium from low-enriched uranium feed might be accomplished more effectively in two separate cascades—one that enriches natural uranium to a few percent and another that enriches this product to weapon grade. If Pakistan had dedicated only 700 centrifuges to producing 5 percent enriched uranium from the beginning of 1984 through 1986, it could have produced about 1,200 kilograms of 5 percent enriched product. If it now uses 400 other centrifuges to enrich the 5 percent product to weapon-grade uranium, Pakistan could produce about 50 kilograms of weapon-grade uranium a year, assuming the waste contained a 1 percent concentration of uranium 235. This is enough weapon-grade material for two nuclear explosives.

If Pakistan continues to produce weapon-grade uranium it could accumulate enough over the next few years for several nuclear weapons. If next year alone Pakistan operates slightly more than 1,000 centrifuges arranged to produce weapon-grade uranium from natural uranium, it could produce enough material for one weapon. If it further enriches a stockpile of low-enriched uranium, however, it could increase this number to two weapons.

Pakistan probably is concentrating on operating more centrifuges. If the *Muslim* report is correct, and Pakistan succeeds in operating 3,000 centrifuges, it could produce two to three weapons a year using natural uranium feed. ☐

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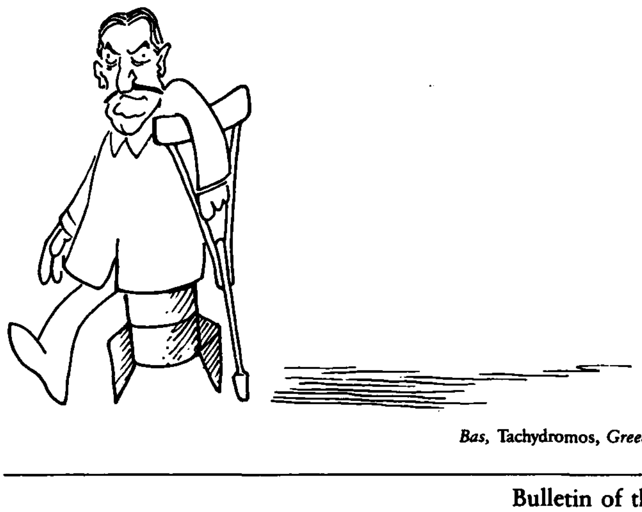

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